NASA TECHNICAL TRANSLATION

NASA TT F-14,878

SPECIFIC IMPULSE OF MINIATURE MOTORS EMPLOYING CRYOGENIC FUELS

P. V. Semenikhin

Translation of: "Udel'nyy impul's mikrodvigateley na kriogennom toplive," Izvestiya Vysshikh Uchebnykh Zavedeniy, Aviatsionnaya Tekhnika, Vol. 14, No. 3, 1971, pp 50-53

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 APRIL 1973

STANDARD TITLE PAGE

1. Report No. NASA TT F-14,878	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle SPECIFIC IMPULSE OF MINIATURE MOTORS EMPLOYING CRYOGENIC FUELS		5. Report Date 16 April 1973
		6. Performing Organization Code
7. Author(s) P. V. Semenikhin		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address SCITRAN, P. O. Box 5456 Santa Barbara, Ca. 93108		11. Contract or Grant No. NASW 2483
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, Washington, D. C.		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Udel'nyi impul's mikrodvigatelei na kriogennom toplive," Izvestiya Vysshikh Uchebnykh Zavedeniy, Aviatsionnaya Tekhnika, Vol 14, No. 3, 1971, pp 50-53

16. Abstract

Auxiliary rocket thrusters in which large mass savings are achieved by using liquefied gases as the propellant are examined. A method of evaluating the mass characteristics of such systems is proposed, along with methods of evaluating propellant efficiency. Estimates of the specific impulse obtainable with various propellants are obtained.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified - Unlimited

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 10	22. Price 3.00

NASA-HQ

SPECIFIC IMPULSE OF MINIATURE MOTORS
EMPLOYING CRYOGENIC FUELS

P. V. Semenikhin

The literature [1], [2] contains certain information on the possible specific parameters of miniature rocket motors using cryogenic fuels. Single-component cold systems are examined, i.e., systems in which the fuel does not burn in the chamber. /50*

When comparing the different fuels, we have the following expression for the effective specific impulse

$$I_{sp} = \frac{P_{sp}}{1 + 1.5\frac{1}{\sigma}\frac{p_s}{\gamma_T}} \qquad (1)$$

where γ is the density of the material used in the fuel tank;

σ — permissible stress in the tank material;

P_s — pressure of saturated fuel vapors;

γ_T — fuel density;

P_{sp} — specific thrust developed by the engine on this fuel.

Based on analysis of the different cryogenic fuels, relationship (1) may be used to give certain recommendations on selecting the most effective fuel.

*Numbers in the margin indicate pagination of original foreign text.

Relationship (1) is established under the assumption that the mass of a motor using a cryogenic fuel is composed of the mass of the fuel and the mass of the fuel tank, i.e.,

$$G_1 = G_{T_1} + G_{\sigma_1}, \tag{2}$$

where G_{σ_1} is the tank mass;

G_{T_1} — fuel mass.

This is not completely true. Actually, the mass of the tank and the fuel is calculated according to the formula

$$G_{T_1} = \gamma_T V_T, \tag{3}$$

$$G_{\sigma_1} = 1{,}5 \frac{1}{\sigma} p_s V_T, \tag{4}$$

where V_T is the fuel volume.

We thus have

$$G_{\sigma_1} = 1{,}5 \frac{1}{\sigma} \frac{p_s}{\gamma_T} G_{T_1} = m_1 G_{T_1}. \tag{5}$$

The total impulse of the system is

$$I = P_{sp_1} \cdot G_{T_1}. \tag{6}$$

Substituting the values of the terms in I from (6), (5), and (4), we obtain Relationship (1).

If this equation is valid, we can then reach the following conclusion.

In cold pneumatic systems, their mass is primarily determined /51 by the mass of the fuel and the mass of the tanks, i.e.,

$$G_2 = G_{b_2} + G_{T_2}, \tag{7}$$

since

$$G_{b_2} = 1.5 \frac{1}{g} RT_i G_{m_2}, \tag{8}$$

where R is the fuel-constant;

T_i — its initial temperature.

Then the mass of the pneumatic system may be written as

$$G_2 = G_{T_2}(1 + m_2), \tag{9}$$

where

$$m_2 = \frac{G_{b_2}}{G_{T_2}}.$$

The specific impulse of the pneumatic system is

$$I_{sp_2} = \frac{P_{sp_2}}{1 + m_2} \tag{10}$$

For a cryogenic system, in accordance with (5), (4), (2), and (1), the specific impulse may be represented as

$$I_{sp_1} = \frac{P_{sp_1}}{1 + m_1} \tag{11}$$

Let us find the ratio between the specific impulses of the systems. In agreement with (10) and (11), we obtain

$$z = \frac{\frac{P_{sp_1}}{1+m_1}}{\frac{P_{sp_2}}{1+m_2}} \tag{12}$$

With identical fuels and one and the same parameters of the gas in front of the nozzle, we have

$$P_{sp_1} = P_{sp_2}.$$

and

$$z = \frac{1+m_2}{1+m_1}. \tag{13}$$

Since $m_2 \gg 1$, (13) may be written as

$$z \approx \frac{m_2}{m_1} \tag{14}$$

and

$$I_{sp_1} = \frac{m_2}{m_1} I_{sp_2}. \tag{15}$$

Calculating z for certain fuels gives the following values:

(a) for hydrogen z = 500;

(b) for nitrogen z = 70.

As calculations show [3], the value of the specific impulse for gaseous nitrogen is 176.

Thus, when changing to liquified nitrogen, if (1) holds, we obtain the specific impulse

$$I_{sp_1} = 176 \cdot 70 = 12 \cdot 300 \frac{N \cdot sec}{kg}$$

As may be seen, this value of the impulse is not realistic. /52 An estimate of the specific parameters using (1) may lead to great error, both in estimating the mass of the engine, and in selecting the most economical fuel. This may be explained by the fact that relationship (1) does not include several values which determine the mass of the system.

A cryogenic fuel cannot be stored in ordinary tanks, since it boils at low temperatures. Therefore, tanks with the fuel must be insulated. The mass of such tanks will differ greatly from that determined by relationship (4). Insulation of the tank does not exclude the flow of heat to the fuel, i.e., evaporation of the fuel is unavoidable. Fuel losses from evaporation must be taken into account in the general mass of the system, since part of the fuel vapors will be discarded while retaining the pressure in the tank constant. These losses depend on the heat exchange between the tank and the outside environment, the thrust level, and the engine operational mode.

For evaporation of fuel, it is necessary to expend a certain amount of energy before it enters the nozzle, and also a device is necessary for heating and evaporation, i.e., a heat exchanger. The energy consumption for evaporation and heating of a liquid gas is determined by the specific heat, liquid density, and latent heat of the vaporization. This energy may be obtained from the energy sources on board, which increases the total mass of the system or, for example, from the sun, electron devices when they are cooled, etc.

All of this — the energy source and the heat exchanger — also are included in the general mass of the system with cryogenic fuel. Thus, in general form the mass of a system with cryogenic fuel will be determined by the sum of all the given values, i.e.,

$$G = G_T + G_\delta + G_i + G_{se} + G_{TO} + G_l, \tag{16}$$

where G_i, G_{TO}, G_{se}, and G_l are the masses of the insulation for the tanks, the heat exchanger, the energy source, and the fuel loss.

The specific effective impulse is given from the following

$$I_{sp} = \frac{P_{sp}}{1 + \bar{G}_\delta + \bar{G}_i + \bar{G}_{se} + \bar{G}_{TO} + \bar{G}_l}, \tag{17}$$

where

$$\bar{G}_\delta = \frac{G_\delta}{G_T},$$

$$\bar{G}_i = \frac{G_i}{G_T},$$

$$\bar{G}_{TO} = \frac{G_{TO}}{G_T},$$

$$\bar{G}_{se} = \frac{G_{se}}{G_T},$$

$$\bar{G}_l = \frac{G_l}{G_T}.$$

The term I_{sp}, as a function of the relative masses, provides a convenient form for rapidly determining the effectiveness of a certain fuel and the mass of the system for a known total impulse. Usually, an analysis of the control system gives the magnitude of the total impulse or the thrust level, the time, and the off-duty factor of the engine. The total impulse is determined by the formula /53

$$I = G_T \cdot P_{sp} = P \cdot \Delta\tau, \quad (18)$$

where P is the engine thrust;

Δ — off-duty factor; and

τ — time.

Then the mass of the engine may be written as

$$G = \frac{G_T \cdot P_{sp}}{I_{sp}} \quad (19)$$

Calculations using this method for a system utilizing solar energy have shown that in the region of moderate total impulse values around 40,000 to 70,000 N sec and a thrust level of 3.0 to 5.0 N on liquid nitrogen, we may obtain a specific impulse which is approximately four times greater than in a system with a gas fuel.

To a great extent, the specific impulse depends on the operational time, the engine thrust level, and the off-duty factor.

REFERENCES

1. Voprosy raketnoy tekhniki, No. 2, 1962, p. 7; No. 6, 1963 and 1964.

2. Astronavtika i raketnyye dvigateli, No. 27, 1967.

3. Semenikhin, P. V. IVUZ, Aviatsionnaya tekhnika, No. 2, 1966.

Translated for National Aeronautics and Space Administration under contract No. NASW 2483, by SCITRAN, P. O. Box 5456, Santa Barbara, California, 93108.